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(54) Displacement detection apparatus

Vorrichtung zur Detektion einer Verschiebung

Appareil de détection de déplacement

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Description

The present invention relates to an apparatus for optically detecting a displacement (a moving amount, rotational amount, velocity, and acceleration) of an object and, more particularly, to an encoder, a velocity sensor, an acceleration sensor, and the like.

Optical displacement sensors such as an optical encoder, a laser Doppler velocimeter, a laser interferometer, and the like for obtaining a displacement of an object with high precision by irradiating light onto the object have been widely used in the fields of NC machine tools, OA equipment, robots, precision manufacturing apparatuses, and the like.

In one of such displacement sensors, 0th- and 1st-order diffracted light beams obtained by diffracting a laser beam by a first diffraction grating are irradiated onto a second diffraction grating formed on a scale. A +1st-order reflectively diffracted light beam generated by reflectively diffracting the 0th-order diffracted light beam by the second diffraction grating, and a -1st-order reflectively diffracted light beam generated by reflectively diffracting the 1st-order diffracted light beam by the second diffraction grating are directed toward a third diffraction grating arranged near the first diffraction grating. The third diffraction grating synthesizes the +1st- and -1st-order reflectively diffracted light beams to form an interference light beam, and the interference light beam is photoelectrically converted to obtain a sine wave signal representing the displacement of the scale.

In the above-mentioned displacement sensor, since the first and second diffraction gratings are supported by different members, the parallelness between the first and second diffraction gratings is low, and the incident positions of the +1st- and -1st-order reflectively diffracted light beams on the third diffraction grating cannot coincide with each other, resulting in a low intensity of the interference light beam. Therefore, the sine wave signal obtained by photoelectric conversion has a low S/N ratio.

Furthermore, from document EP-A-0 333 929 a photoelectric position detection device having a three grating arrangement is known, which device evaluates light beams intensity modulated due to interference. However, this prior art arrangement requires a predetermined angle of incidence for an incident light beam impinging on a first grating, thus necessitating the light source and the detection device to be accurately aligned with respect to each other.

Hence, it as an object of the present invention to provide a displacement detection apparatus which is free of the above mentioned problems.

This object is achieved by a displacement detection apparatus according to claim 1.

Advantageous further developments are as set out in the dependent claims.

In particular, according to a preferred aspect of the present invention, the synthesizing means comprises a third diffraction grating for achieving the synthesis, and if grating pitches of the first, second, and third diffraction gratings are represented by P1, P2, and P3, the grating pitches substantially satisfy the following condition:

$$|P1 - P2| \cdot P3 = P1 \cdot P2$$

According to another preferred aspect of the present invention, the second diffraction grating is designed to reflectively diffract the two beams, and the first diffraction grating is formed on a surface, on the side of the third diffraction grating, of the substrate.

According to still another preferred aspect of the present invention, the second diffraction grating is designed to reflectively diffract the two beams, and the first diffraction grating is formed on a surface, on the side opposite to the third diffraction grating, of the substrate.

According to still another preferred aspect of the present invention, the second diffraction grating is designed to transmit the two beams, and the first diffraction grating is formed on a surface, on the side of the third diffraction grating, of the substrate.

According to still another preferred aspect of the present invention, the second diffraction grating is designed to transmit the two beams, and the first diffraction grating is formed on a surface, on the side opposite to the third diffraction grating, of the substrate.

Fig. 1 is a schematic perspective view showing the first embodiment of the present invention;

Figs. 2A and 2B are explanatory views showing the first embodiment of the present invention, in which Fig. 2A is a front view, and Fig. 2B is a side view;

Fig. 3 is a schematic perspective view showing the second embodiment of the present invention;

Figs. 4A and 4B are explanatory views showing the second embodiment of the present invention, in which Fig. 4A is a front view, and Fig. 4B is a side view;

Fig. 5 is a schematic perspective view showing the third embodiment of the present invention;

Figs. 6A and 6B are explanatory views showing the third embodiment of the present invention, in which Fig. 6A is a front view, and Fig. 6B is a side view;

Fig. 7 is a schematic perspective view showing the fourth embodiment of the present invention;
Figs. 8A and 8B are explanatory views showing the fourth embodiment of the present invention, in which Fig. 8A is a front view, and Fig. 8B is a side view;
Fig. 9 is a schematic perspective view showing the fifth embodiment of the present invention;
Figs. 10A and 10B are explanatory views showing the fifth embodiment of the present invention, in which Fig. 10A is a front view, and Fig. 10B is a side view;
Fig. 11 is a schematic perspective view showing the sixth embodiment of the present invention;
Figs. 12A and 12B are explanatory views showing the sixth embodiment of the present invention, in which Fig. 12A is a front view, and Fig. 12B is a side view;
Fig. 13 is a schematic perspective view showing the seventh embodiment of the present invention;
Figs. 14A and 14B are explanatory views showing the seventh embodiment of the present invention, in which Fig. 14A is a front view, and Fig. 14B is a side view; and
Fig. 15 is a block diagram showing an example of a drive system comprising the displacement detection apparatus of the present invention.

Fig. 1 is a schematic perspective view showing the first embodiment of the present invention, and Figs. 2A and 2B are respectively a front view and a side view of an apparatus shown in Fig. 1.

The apparatus of this embodiment comprises a light-emitting element 1 such as a light-emitting diode, a laser diode, or the like, a light-receiving element 3 for photoelectrically converting an interference beam, and outputting a displacement detection signal (sine wave signal), a first diffraction grating G1 for splitting a divergent light beam emitted from the light-emitting element 1, a second diffraction grating G2, having a grating pitch different from that of the first diffraction grating G1, for deflecting the split divergent light beams by reflectively diffracting the light beams, a third diffraction grating G3, formed on a light-receiving portion of the light-receiving element 3, for synthesizing the light beams, a mask 6 arranged between the light-emitting element 1 and the first diffraction grating G1 to intercept unnecessary light components, and a scale 10 in which the diffraction grating G1 is formed on one surface, on the side of the members 1, 3, 6, and G3, of a transparent parallel plate, and the diffraction grating G2 is formed on the opposite surface of the transparent parallel plate. A portion of the divergent light beam emitted from the light-emitting element 1 passes through the mask 6, and the passed light beam is subjected to phase modulation, i.e., is diffracted at a point 01 of the diffraction grating G1 on the surface, on the side of the element 1, of the scale 10, and is split into +1st- and -1st-order diffracted light beams R+1 and R-1. The phase of the +1st-order diffracted light beam R+1 is shifted by $+2\pi x/P1$, and the phase of the -1st-order diffracted light beam R-1 is shifted by $-2\pi x/P1$ (where x is the moving distance of the scale).

The +1st-order diffracted light beam R+1 becomes incident on a point 02 of the diffraction grating G2 formed on the surface, opposite to the surface on which the diffraction grating G1 is formed, of the scale 10, and is reflectively diffracted and split into a -1st-order diffracted light beam R+1-1 and other light beams. The -1st-order diffracted light beam R-1 becomes incident on a point 03 of the diffraction grating G2, and is reflectively diffracted and split into a +1st-order diffracted light beam R-1+1 and other light beams. The phase of the -1st-order diffracted light beam R+1-1 from the point 02 is shifted by $-2\pi x/P2$ by diffraction at the point 02, and becomes $2\pi x(1/P1-1/P2)$. The phase of the +1st-order diffracted light beam R-1+1 is shifted by $2\pi x/P2$ by diffraction at the point 03, and becomes $2\pi x(-1/P1+1/P2)$. The -1st-order diffracted light beam R+1-1 becomes incident on the diffraction grating G3 of the light-receiving element 3, is transmissively diffracted by the diffraction grating G3, and is split into a -1st-order diffracted light beam R+1-1-1, and other light beams. The +1st-order diffracted light beam R-1+1 becomes incident on the diffraction grating G3 of the light-receiving element 3, is transmissively diffracted by the diffraction grating G3, and is split into a -1st-order diffracted light beam R-1+1-1, and other light beams. Of the transmissively diffracted light beams, the -1st-order diffracted light beams R+1-1-1 and R-1+1-1 which are synthesized by overlapping their optical paths become incident on the light-receiving element 3 as an interference light beam. The phase of the interference light beam at this time is given by:

$$2\pi x(1/P1-1/P2) - 2\pi x(-1/P1+1/P2)$$

$$= 4\pi x(1/P1-1/P2)$$

$$= 4\pi x/P3$$

Thus, every time the first and second diffraction gratings G1 and G2 on the scale 10 simultaneously move by a pitch 1/2 of that of the third diffraction grating G3, a brightness change for one period occurs.

In this embodiment, when the pitches of the three diffraction gratings G1, G2, and G3 are respectively represented

by P1, P2, and P3, the diffraction gratings G1, G2, and G3 are designed to satisfy a condition $P3 = P1 \cdot P2/|P1-P2|$(e. g., $P1 = 4$ μm, $P2 = 2$ μm, and $P3 = 4$ μm). Thus, as can be seen from the above description, an encoder with a resolution of 2 μm can be realized.

In this embodiment, the first and second diffraction gratings G1 and G2 are separately formed on the opposite parallel surfaces of the transparent parallel-plate substrate 10, and the parallelness between the first and second diffraction gratings G1 and G2 is high since they are formed on the parallel surfaces of the common substrate, resulting in a high detection sensitivity (S/N ratio).

The apparatus of this embodiment has a very simple interference optical system arrangement. When the two diffraction gratings G1 and G2 are formed on the two surfaces of a glass (scale 10) by, e.g., a replica method, a compact, simple-structured, and inexpensive encoder can be realized. Since a head portion is constituted by only the light-emitting element 1 and the light-receiving element 3 with the third diffraction grating G3, the number of components is small, and assembling is easy, thus providing a very compact, low-cost encoder. When the diffraction grating G1 comprises a phase grating, and a depth d of the steps of the grating is set to satisfy $d = \lambda/\{2(n-1)\}$ (n is the refractive index of the grating, and λ is the wavelength), 0th-order light can be almost eliminated from light beams diffracted and split by the diffraction grating G1, and only ±1st-order diffracted light beams can be obtained.

Fig. 3 is a schematic perspective view showing the second embodiment of the present invention, and Figs. 4A and 4B are respectively a front view and a side view of an apparatus shown in Fig. 3.

The apparatus of this embodiment comprises a light-emitting element 1 such as a light-emitting diode, a laser diode, or the like, a light-receiving element 3 for photoelectrically converting an interference beam, and outputting a displacement detection signal (sine wave signal), a first diffraction grating G1 for splitting a divergent light beam emitted from the light-emitting element 1, a second diffraction grating G2, having a grating pitch different from that of the first diffraction grating G1, for deflecting the split divergent light beams by reflectively diffracting the light beams, a third diffraction grating G3, formed on a light-receiving portion of the light-receiving element 3, for synthesizing the light beams, and a scale 10 in which the diffraction grating G1 is formed on one surface, on the side opposite to the members 1, 3, and G3, of a transparent parallel plate, and the diffraction grating G2 is formed on the other surface, on the side of the members 1, 3, and G3, of the transparent parallel plate.

Since the basic principle for forming an interference beam in this embodiment is the same as that in the above embodiment, and can be easily understood from the optical path diagrams of Figs. 4A and 4B, a detailed description thereof will be omitted.

This embodiment, as well, can provide the same effect as that in the above embodiment. As shown in Fig. 3, the diffraction gratings G1 and G2 on the scale are arranged on the opposite sides of the scale to assure the distance between the scale and the head. In the preferred aspect of this embodiment, grating pitches P1, P2, and P3 of the diffraction gratings G1, G2, and G3 satisfy a condition $P3 = P1 \cdot P2/|P1-P2|$.

Fig. 5 is a schematic perspective view showing the third embodiment of the present invention, and Figs. 6A and 6B are respectively a front view and a side view of an apparatus shown in Fig. 5.

The apparatus of this embodiment comprises a light-emitting element 1 such as an LED, a laser diode, or the like, a light-receiving element 3 for photoelectrically converting an interference light beam, and outputting a displacement detection signal, a first diffraction grating G1 for splitting a divergent light beam emitted from the light-emitting element 1, a second diffraction grating G2, having a grating pitch different from that of the first diffraction grating, for deflecting the split divergent light beams by transmissively diffracting the light beams, a third diffraction grating G3, formed on a light-receiving portion of the light-receiving element 3, for synthesizing the light beams, and a scale 10 in which the diffraction grating G1 is formed on one surface, on the side of the member 1, of a transparent parallel plate, and the diffraction grating G2 is formed on the other surface, on the side of the members 3 and G3, of the transparent parallel plate.

Since the basic principle for forming an interference beam in this embodiment is the same as that in the above embodiments, and can be easily understood from the optical path diagrams of Figs. 6A and 6B, a detailed description thereof will be omitted.

In the preferred aspect of this embodiment, grating pitches P1, P2, and P3 of the diffraction gratings G1, G2, and G3 satisfy a condition $P3 = P1 \cdot P2/|P1-P2|$.

This embodiment can also provide the same effect as that in the above embodiments.

Fig. 7 is a schematic perspective view showing the fourth embodiment of the present invention, and Figs. 8A and 8B are respectively a front view and a side view of an apparatus shown in Fig. 7.

The apparatus of this embodiment comprises a light-emitting element 1 such as an LED, a laser diode, or the like, a mirror surface 2, a light-receiving element 3 for photoelectrically converting an interference light beam, and outputting a displacement detection signal (sine wave signal), a first diffraction grating G1 for splitting a divergent light beam emitted from the light-emitting element 1, a second diffraction grating G2, having a grating pitch different from that of the first diffraction grating, for deflecting the split divergent light beams by transmissively diffracting the light beams, a third diffraction grating G3, formed on a light-receiving portion of the light-receiving element 3, for synthesizing light

beams, a mask 6, arranged between the light-emitting element 1 and a scale 10, for intercepting unnecessary light components, and the scale 10 which has the diffraction gratings G1 and G2 on a surface, on the side of the light-emitting element 1 and the light-receiving element 3, of a transparent parallel plate, and has the mirror surface 2 on the opposite surface.

A portion of the divergent light beam emitted from the light-emitting element 1 passes through the mask 6, and undergoes phase modulation, i.e., is diffracted and split into +1st- and -1st-order diffracted light beams R+1 and R-1 at a point 01 on the diffraction grating G1 on the surface of the scale 10. The phase of the +1st-order diffracted light beam R+1 is shifted by $+2\pi x/P1$, and the phase of the -1st-order diffracted light beam R-1 is shifted by $-2nx/P1$ (where x is the moving distance of the scale).

The +1st-order diffracted light beam R+1 is reflected by a point 02 on the mirror surface 2, on the side opposite to the diffraction grating G1, of the scale 10, and becomes incident on a point 04 of the diffraction grating G2. The +1st-order diffracted light beam R+1 is transmissively diffracted by the diffraction grating G2, and is split into a -1st-order diffracted light beam R+1-1 and other light beams. Also, the -1st-order diffracted light beam R-1 is reflected by a point 03 on the mirror surface 2, on the side opposite to the diffraction grating G1, of the scale 10, and becomes incident on a point 05 of the diffraction grating G2. The -1st-order diffracted light beam R-1 is transmissively diffracted by the diffraction grating G2, and is split into a +1st-order diffracted light beam R-1+1 and other light beams. The phase of the -1st-order diffracted light beam R+1-1 is shifted by $-2\pi x/P2$ by diffraction at the point 04, and becomes $2\pi x(1/P1-1/P2)$. The phase of the +1st-order diffracted light beam R-1+1 is shifted by $2\pi x/P2$ by diffraction at the point 05, and becomes $2\pi x(-1/P1+1/P2)$. The -1st-order diffracted light beam R+1-1 becomes incident on and is transmissively diffracted by the diffraction grating G3, and is split into a -1st-order diffracted light beam R+1-1-1 and other light beams. Also, the +1st-order diffracted light beam R-1+1 becomes incident on and is transmissively diffracted by the diffraction grating G3, and is split into a -1st-order diffracted light beam R-1+1-1 and other light beams. Of the transmissively diffracted light beams, the diffracted light beams R+1-1-1 and R-1+1-1 which are synthesized by overlapping their optical paths become incident on the light-receiving element 3 as an interference light beam. The phase of the interference light beam at this time is given by:

$$\begin{aligned} &2\pi x(1/P1-1/P2) - 2\pi x(-1/P1+1/P2) \\ &= 4\pi x(1/P1-1/P2) \\ &= 4\pi x/P3 \end{aligned}$$

Thus, every time the first and second diffraction gratings G1 and G2 on the scale 10 simultaneously move by a pitch 1/2 of that of the third diffraction grating G3, a brightness change for one period occurs.

In this embodiment, when the pitches of the three diffraction gratings G1, G2, and G3 are respectively represented by P1, P2, and P3, the diffraction gratings G1, G2, and G3 are designed to satisfy a condition $P3 = P1 \cdot P2/|P1-P2|$. For example, if P1 = 4 μm, P2 = 2 μm, and P3 = 4 μm, an encoder with a resolution of 2 μm can be realized.

In this embodiment, the first and second diffraction gratings G1 and G2 are separately formed on a single surface of a transparent parallel-plate substrate (scale 10), and the parallelness between the first and second diffraction gratings G1 and G2 is high, resulting in a high detection sensitivity (S/N ratio).

The apparatus of this embodiment has a very simple interference optical system arrangement. When the two diffraction gratings G1 and G2 are formed on a single surface of a glass (scale 10) by, e.g., a replica method, the manufacture of diffraction gratings is facilitated. Since the diffraction gratings G1 and G2 are formed on a single surface, the head portion and the scale 10 can be easily mounted. When the diffraction grating G1 comprises a phase grating, and a depth d of the steps of the grating is set to satisfy $d = \lambda/\{2(n-1)\}$, 0th-order light can be almost eliminated from light beams diffracted and split by the diffraction grating G1, and only ±1st-order diffracted light beams can be obtained (n is the refractive index of the grating, and λ is the central wavelength of light emitted from the light-emitting element 1).

Fig. 9 is a schematic perspective view showing the fifth embodiment of the present invention, and Figs. 10A and 10B are respectively a front view and a side view of an apparatus shown in Fig. 9.

The apparatus of this embodiment comprises a light-emitting element 1 such as a laser diode, a light-emitting diode, or the like, a mirror 2 separately arranged above a scale 10, a light-receiving element 3 for photoelectrically converting an interference light beam, and outputting a displacement detection signal, a first diffraction grating G1 for splitting a divergent light beam emitted from the light-emitting element 1, a second diffraction grating G2, having a grating pitch different from that of the first diffraction grating G1, for deflecting the split divergent light beams by transmissively diffracting the light beams, a third diffraction grating G3 for synthesizing light beams, and the scale 10 in which the first and second diffraction gratings G1 and G2 are formed on a surface, on the side of the light-emitting element 1 and the light-receiving element 3, of a transparent parallel plate.

Since the basic principle for forming an interference beam in this embodiment is the same as that in the above-mentioned fourth embodiment, and can be easily understood from the optical path diagrams of Figs. 10A and 10B, a detailed description thereof will be omitted.

In the preferred aspect of this embodiment, grating pitches P1, P2, and P3 of the diffraction gratings G1, G2, and G3 satisfy a condition P3 = P1·P2/|P1-P2|.

This embodiment can also provide the same effect as that in the fourth embodiment.

Fig. 11 is a schematic perspective view showing the sixth embodiment of the present invention, and Figs. 12A and 12B are respectively a front view and a side view of an apparatus shown in Fig. 11.

The apparatus of this embodiment comprises a light-emitting element 1 such as a semiconductor laser, an LED, or the like, a mirror 2 formed on the surface, on the side of the light-emitting element 1, of a scale 10, a light-receiving element 3 for detecting a displacement detection signal by photoelectrically converting an interference light beam, a first diffraction grating G1 for splitting a divergent light beam emitted from the light-emitting element 1, a second diffraction grating G2, having a grating pitch different from that of the first diffraction grating G1, for deflecting the split divergent light beams by reflectively diffracting the light beams, a third diffraction grating G3, formed on a light-receiving portion of the light-receiving element 3, for synthesizing light beams, and the scale 10 in which the first and second diffraction gratings G1 and G2 are formed on a surface, on the side opposite to the light-emitting element 1 and the light-receiving element 3, of a transparent parallel plate. A portion of the divergent light beam emitted from the light-emitting element 1 passes through a mask 6, and the passed light beam is subjected to phase modulation, i.e., is reflectively diffracted at a point 01 of the diffraction grating G1 on the rear surface of the scale 10, and is split into +1st- and -1st-order diffracted light beams R+1 and R-1. The phase of the +1st-order diffracted light beam R+1 is shifted by $+2\pi x/P1$, and the phase of the -1st-order diffracted light beam R-1 is shifted by $-2\pi x/P1$ (where x is the moving distance of the scale).

The +1st-order diffracted light beam R+1 is reflected by a point 02 on the mirror surface 2 formed on the front surface of the scale 10, and becomes incident on a point 04 of the diffraction grating G2. The +1st-order diffracted light beam R+1 is transmissively diffracted by the diffraction grating G2, and is split into a -1st-order diffracted light beam R+1-1 and other light beams. Also, the -1st-order diffracted light beam R-1 is reflected by a point 03 on the mirror surface 2 formed on the front surface of the scale 10, and becomes incident on a point 05 of the diffraction grating G2. The -1st-order diffracted light beam R-1 is transmissively diffracted by the diffraction grating G2, and is split into a +1st-order diffracted light beam R-1+1 and other light beams. The phase of the -1st-order diffracted light beam R+1-1 is shifted by $-2\pi x/P2$ by diffraction at the point 04, and becomes $2\pi x(1/P1-1/P2)$. The phase of the +1st-order diffracted light beam R-1+1 is shifted by $2\pi x/P2$ by diffraction at the point 05, and becomes $2\pi x(-1/P1+1/P2)$. The -1st-order diffracted light beam R+1-1 becomes incident on and is transmissively diffracted by the diffraction grating G3, and is split into a -1st-order diffracted light beam R+1-1-1 and other light beams. Also, the +1st-order diffracted light beam R-1+1 becomes incident on and is transmissively diffracted by the diffraction grating G3, and is split into a -1st-order diffracted light beam R-1+1-1 and other light beams. Of the transmissively diffracted light beams, the diffracted light beams R+1-1-1 and R-1+1-1 which are synthesized by overlapping their optical paths become incident on the light-receiving element 3 as an interference light beam. The interference phase at this time is given by:

$$2\pi x(1/P1-1/P2) - 2\pi x(-1/P1+1/P2)$$

$$= 4\pi x(1/P1-1/P2)$$

Thus, every time the first and second diffraction gratings G1 and G2 on the scale 10 simultaneously move by a pitch 1/2 of that of the third diffraction grating G3, a brightness change for one period occurs.

In this embodiment, when the pitches of the three diffraction gratings G1, G2, and G3 are respectively represented by P1, P2, and P3, the diffraction gratings G1, G2, and G3 are designed to satisfy a condition P3 = P1·P2/|P1-P2|. For example, if P1 = 4 μm, P2 = 2 μm, and P3 = 4 μm, an encoder with a resolution of 2 μm can be realized.

In this embodiment, an interference optical system has a very simple arrangement, and when the two diffraction gratings are formed on a single surface of a glass (scale 10), the manufacture of the diffraction gratings is facilitated. Since the diffraction gratings G1 and G2 are formed on a single surface, the parallelness between the two diffraction gratings can have remarkably high precision, and the sensitivity (S/N) of the detection signal can be improved. Thus, the influence of a mounting error between the head portion and the scale on the output can be eliminated, and the head portion and the scale can be easily mounted.

Since the diffraction gratings G1 and G2 are formed as reflection type diffraction gratings on the rear surface of the scale 10, the influence of, e.g., dust attached to the gratings on the output signal can be eliminated. Furthermore, when a portion above the gratings G1 and G2 is covered with, e.g., a cover glass, the diffraction gratings can be protected.

When the diffraction gratings G1, G2, and G3 comprise phase gratings, the depth of the grating steps of each of the diffraction gratings G1 and G2 is set to be $\lambda/4n$, and the depth of the grating steps of the diffraction grating G3 is set to be $\lambda/\{2(n-1)\}$, 0th-order diffracted light can be almost eliminated from light beams split by these diffraction gratings, and only ±1st-order diffracted light beams can be obtained (λ is the wavelength, and n is the refractive index of the grating).

Since the diffraction gratings are formed on the rear surface of the scale, the interval between the scale and the head portion can be shortened, and a further compact structure can be provided.

Fig. 13 is a schematic perspective view showing the seventh embodiment of the present invention, and Figs. 14A and 14B are respectively a front view and a side view of an apparatus shown in Fig. 13.

The apparatus of this embodiment comprises a light-emitting element 1 such as a semiconductor laser, an LED, or the like, a mirror 2 separately arranged below a scale 10, a light-receiving element 3 for outputting a displacement detection signal by photoelectrically converting an interference light beam, a first diffraction grating G1 for splitting a divergent light beam emitted from the light-emitting element 1, a second diffraction grating G2, having a grating pitch different from that of the first diffraction grating G1, for deflecting the split divergent light beams by reflectively diffracting the light beams, a third diffraction grating G3, formed on a light-receiving portion of the light-receiving element 3, for synthesizing the light beams, and the scale 10 in which the first and second diffraction gratings G1 and G2 are formed on a surface, on the side opposite to the light-emitting element 1 and the light-receiving element 3, of a transparent parallel plate.

Since the basic principle for forming an interference beam in this embodiment is the same as that in the above-mentioned sixth embodiment, and can be easily understood from the optical path diagrams of Figs. 14A and 14B, a detailed description thereof will be omitted. This embodiment can also provide the same effect as that in the sixth embodiment. It is preferable that grating pitches P1, P2, and P3 of the diffraction gratings G1, G2, and G3 satisfy a condition $P3 = P1 \cdot P2/|P1-P2|$.

In each of the apparatuses described above with reference to Figs. 1 to 14B, a collimator lens may be arranged between the light-emitting element 1 and the scale 10, so that divergent light emitted from the light-emitting element 1 is collimated by the collimator lens, and the collimated light becomes incident on the scale 10.

In each of the apparatuses described above with reference to Figs. 1 to 14B, the third diffraction grating G3 and the light-receiving portion of the light-receiving element 3 may be separately arranged, and a focusing lens may be arranged therebetween.

Fig. 15 is a system block diagram showing a drive system using the encoder according to an embodiment as an application of the above-mentioned encoder. An encoder 101 is attached to a drive output portion of a drive means 100 having a drive source such as a motor, an actuator, an engine, or the like, or to a moving portion of an object to be driven, and detects a displacement state such as a displacement amount, a displacement velocity, or the like. The encoder comprises one of those described in the above embodiments. The detection output of this encoder 101 is fed back to a control means 102, and the control means 102 supplies a drive signal to the drive means 100, so that a state set by a set up means 103 is attained. With this feedback system, the drive state set by the set up means 103 can be obtained. The drive system can be widely applied to OA equipment such as typewriters, printers, copying machines, facsimile apparatuses, and the like; video equipment such as cameras, video apparatuses, and the like; information recording/reproduction apparatuses; robots; machine tools; manufacturing apparatuses; transport machines; and all other apparatuses having drive means.

Claims

1. A displacement detection apparatus which comprises:

   a light emitting element (1);
   a first diffraction grating (G1) which receives a beam from said light emitting element (1) for splitting said beam into two beams;
   a substrate (10);
   a second diffraction grating (G2) provided on a first surface of said substrate (10) for receiving said two beams and for generating a first diffracted beam upon irradiation of one of the two beams and a second diffracted beam upon irradiation of the other of the two beams;
   synthesising means (G3j for synthesising said first and said second diffracted beams to form an interference beam; and
   means (3) for receiving said interference beam and for converting the interference beam into a signal representing a displacement of said substrate (10),

characterised in that

the first diffraction grating (G1) is arranged on said first surface of said substrate (10) or on another surface of said substrate (10) which is parallel to said first surface.

2. An apparatus according to claim 1, characterised in that the first diffracted beam includes +mth-order diffracted light, and the second diffracted beam includes -mth-order diffracted light; where m is a natural number.

3. An apparatus according to claims 1 or 2, characterised in that the synthesising means comprises a third diffraction grating (G3) for achieving the synthesis.

4. An apparatus according to claim 3, characterised in that said second diffraction grating (G2) is a reflective diffraction grating and formed on a surface of said substrate (10) which is on the opposite side of the substrate (10) with respect to the third diffraction grating (G3).

5. An apparatus according to claim 3, characterised in that said second diffraction grating (G2) is a transmissive diffraction grating and formed on a surface of said substrate (10) which faces said third diffraction grating (G3).

6. An apparatus according to claim 3, characterised in that when the grating pitches of said first, second and third diffraction gratings (G1, G2, G3) are represented by P1, P2 and P3, the grating pitches substantially satisfy the condition:

$$|P1 - P2| * P3 = P1 * P2.$$

7. An apparatus according to claims 2 to 6, characterised in that the first diffracted beam is +1st-order diffracted light, and the second diffracted beam is -1st-order diffracted light.

8. A drive system comprising an apparatus according to claims 1 to 7.

Patentansprüche

1. Vorrichtung zur Detektion einer Verschiebung, welche aufweist:

- ein Lichtabstrahlelement **(1)**,
- ein erstes Beugungsgitter **(G1)**, welches einen Strahl vom Lichtabstrahlelement **(1)** aufnimmt, um den Strahl in zwei Strahlen zu teilen,
- ein Substrat **(10)**,
- ein zweites Beugungsgitter **(G2)**, welches auf einer ersten Oberfläche des Substrats **(10)** ausgebildet ist, zum Aufnehmen der zwei Strahlen und zum Erzeugen eines ersten Beugungsstrahls beim Einstrahlen eines der zwei Strahlen und eines zweiten Beugungsstrahls beim Einstrahlen des anderen der zwei Strahlen,
- eine Zusammensetzeinrichtung **(G3)** zum Zusammensetzen des ersten und des zweiten Beugungsstrahls, um einen Interferenzstrahl zu erzeugen, und
- eine Einrichtung **(3)** zum Aufnehmen des Interferenzstrahls und zum Umwandeln des Interferenzstrahls in ein Signal, welches eine Verschiebung des Substrats **(10)** darstellt,

dadurch gekennzeichnet, daß das erste Beugungsgitter **(G1)** auf der ersten Oberfläche des Substrats **(10)** oder auf einer anderen Oberfläche des Substrats **(10)** angeordnet ist, welche parallel zu der ersten Oberfläche ist.

2. Vorrichtung zur Detektion einer Verschiebung gemäß Anspruch 1,

dadurch gekennzeichnet, daß der erste Beugungsstrahl Beugungslicht +m-ter Ordnung aufweist und der zweite Beugungsstrahl Beugungslicht -m-ter Ordnung aufweist, wobei m eine natürliche Zahl ist.

3. Vorrichtung zur Detektion einer Verschiebung gemäß Anspruch 1 oder 2,

dadurch gekennzeichnet, daß die Zusammensetzeinrichtung ein drittes Beugungsgitter **(G3)** aufweist, um das Zusammensetzen auszuführen.

4. Vorrichtung zur Detektion einer Verschiebung gemäß Anspruch 3,

dadurch gekennzeichnet, daß das zweite Beugungsgitter **(G2)** ein Reflexionsbeugungsgitter ist und auf einer Oberfläche des Substrats **(10)** erzeugt ist, welche auf der entgegengesetzten Seite des Substrats **(10)** mit Bezug auf das dritte Beugungsgitter **(G3)** ist.

5. Vorrichtung zur Detektion einer Verschiebung gemäß Anspruch 3,
dadurch gekennzeichnet, daß das zweite Beugungsgitter **(G2)** ein Transmissionsbeugungsgitter ist und auf einer Oberfläche des Substrats **(10)** erzeugt ist, welche dem dritten Beugungsgitter **(G3)** zugewendet ist.

6. Vorrichtung zur Detektion einer Verschiebung gemäß Anspruch 3,
dadurch gekennzeichnet, daß in dem Fall, wenn die Gitterabstände des ersten Beugungsgitters **(G1)**, des zweiten Beugungsgitters **(G2)** und des dritten Beugungsgitters **(G3)** jeweils mit P1, P2 und P3 bezeichnet sind, die Gitterabstände im wesentlichen die Beziehung erfüllen:

$$|P1 - P2| * P3 = P1 * P2.$$

7. Vorrichtung zur Detektion einer Verschiebung gemäß den Ansprüchen 2 bis 6,
dadurch gekennzeichnet, daß der erste Beugungsstrahl ein Beugungslicht +1. Ordnung ist und der zweite Beugungsstrahl ein Beugungslicht -1. Ordnung ist.

8. Antriebssystem, welches eine Vorrichtung zur Detektion einer Verschiebung gemäß den Ansprüchen 1 bis 7 aufweist.

Revendications

1. Appareil de détection de déplacement qui comporte :

un élément (1) émettant de la lumière ;
un premier réseau (G1) de diffraction qui reçoit un faisceau dudit élément (1) émettant de la lumière pour diviser ledit faisceau en deux faisceaux ;
un substrat (10) ;
un deuxième réseau (2) de diffraction situé sur une première surface dudit substrat (10) pour recevoir lesdits deux faisceaux et pour générer un premier faisceau diffracté sous l'effet d'une irradiation par l'un des deux faisceaux et un second faisceau diffracté sous l'effet d'une irradiation par l'autre des deux faisceaux ;
un moyen (G3) de synthétisation destiné à synthétiser lesdits premier et second faisceaux diffractés pour former un faisceau d'interférence ; et
un moyen (3) destiné à recevoir ledit faisceau d'interférence et convertir le faisceau d'interférence en un signal représentant un déplacement dudit substrat (10),

caractérisé en ce que
ledit premier réseau de diffraction (G1) est agencé sur ladite première surface dudit substrat (10) ou sur une autre surface dudit substrat (10) qui est parallèle à ladite première surface.

2. Appareil selon la revendication 1, caractérisé en ce que le premier faisceau diffracté comprend une lumière diffractée d'ordre +m, et le second faisceau diffracté comprend une lumière diffractée d'ordre -m, où m est un nombre naturel.

3. Appareil selon les revendications 1 ou 2, caractérisé en ce que le moyen de synthétisation comprend un troisième réseau (G3) de diffraction destiné à réaliser une synthèse.

4. Appareil selon la revendication 3, caractérisé en ce que ledit deuxième réseau de diffraction (G2) est un réseau de diffraction réfléchissant et est formé sur une surface dudit substrat (10) qui est située sur le côté opposé dudit substrat (10) par rapport au troisième réseau de diffraction (G3).

5. Appareil selon la revendication 3, caractérisé en ce que ledit deuxième réseau de diffraction (G2) est un réseau de diffraction à transmission et est formé sur une surface dudit substrat (10) qui fait face audit troisième réseau (G3) de diffraction.

6. Appareil selon la revendication 3, caractérisé en ce que, lorsque les pas desdits premier, deuxième et troisième réseaux de diffraction (G1, G2, G3) sont représentés par P1, P2 et P3, les pas des réseaux satisfont sensiblement à la condition :

$$|P1 - P2| * P3 = P1 * P2.$$

7. Appareil selon les revendications 2 à 6, caractérisé en ce que le premier faisceau diffracté est une lumière diffractée d'ordre +1 et le second faisceau diffracté est une lumière diffractée d'ordre -1.

8. Système d'entraînement comportant un appareil selon les revendications 1 à 7.

FIG. 1

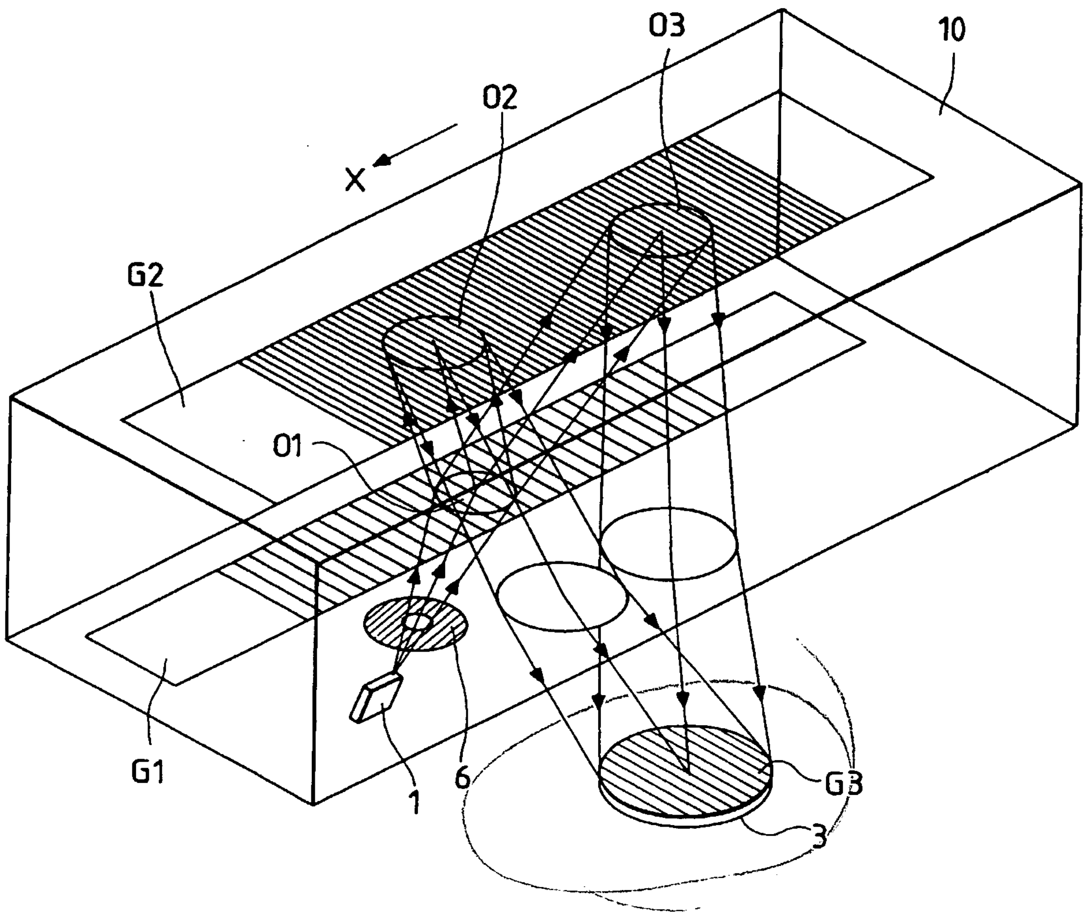


FIG. 2A

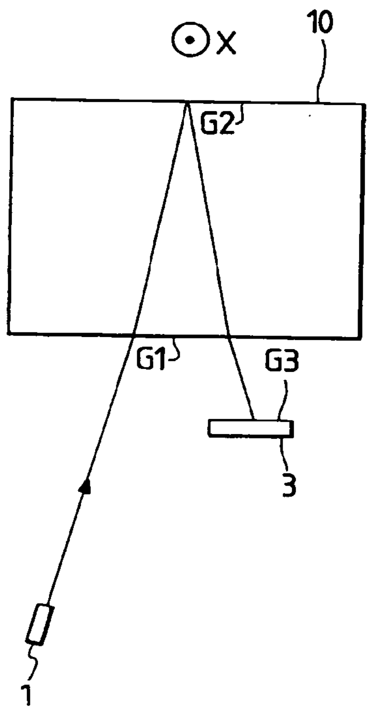


FIG. 2B

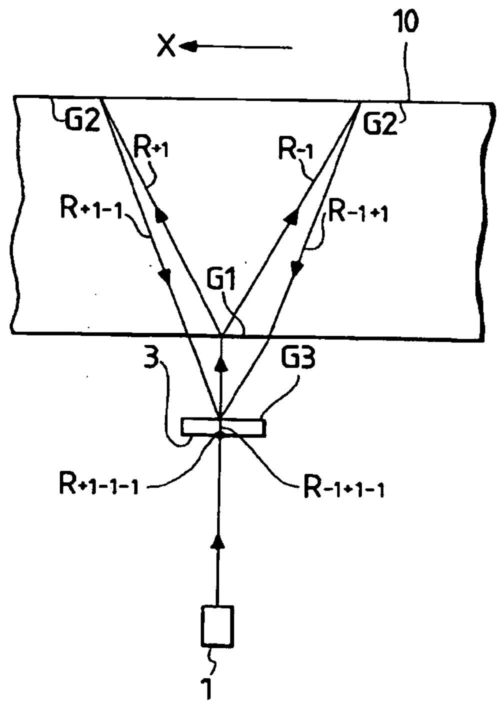


FIG. 3

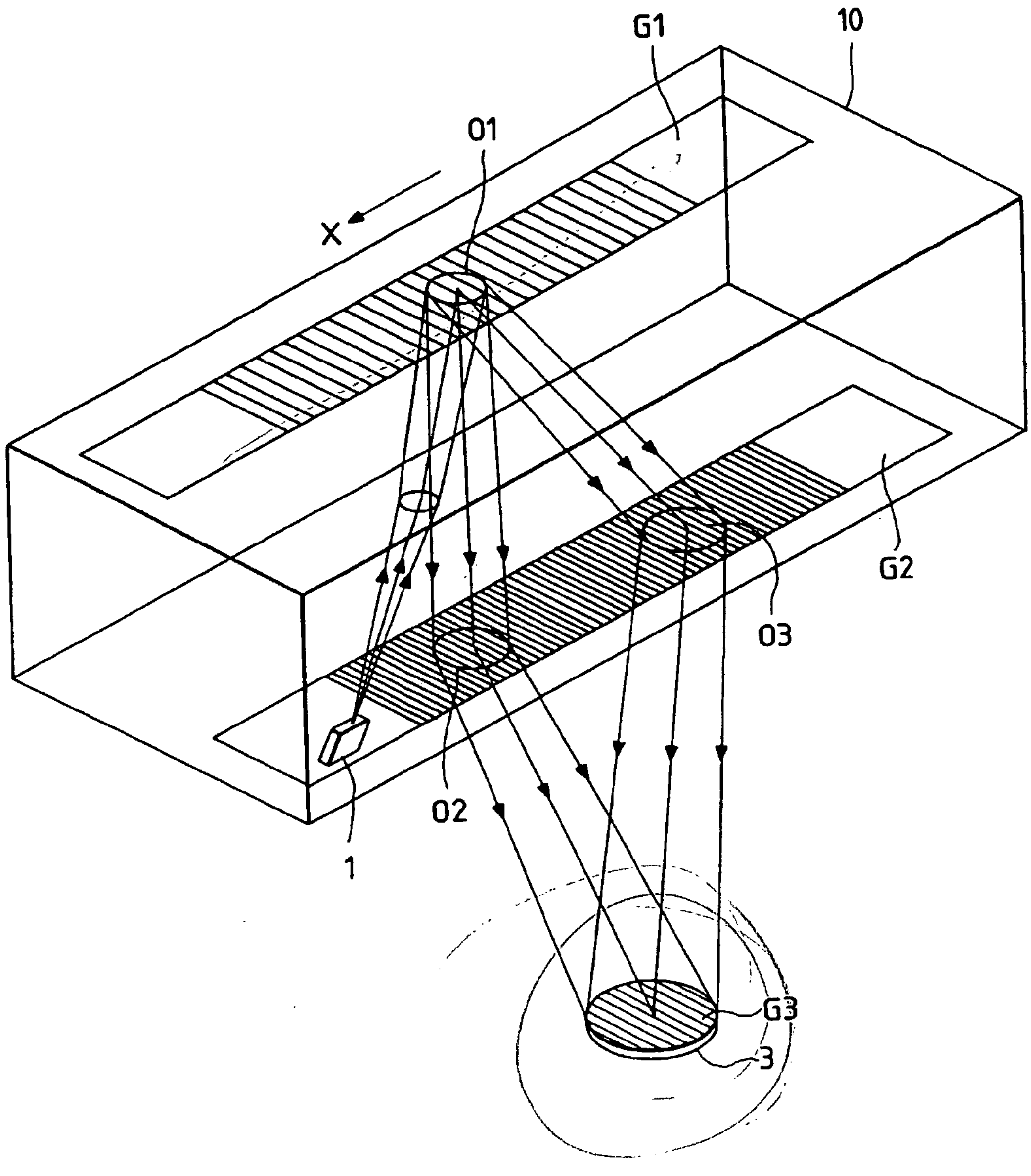


FIG. 4A

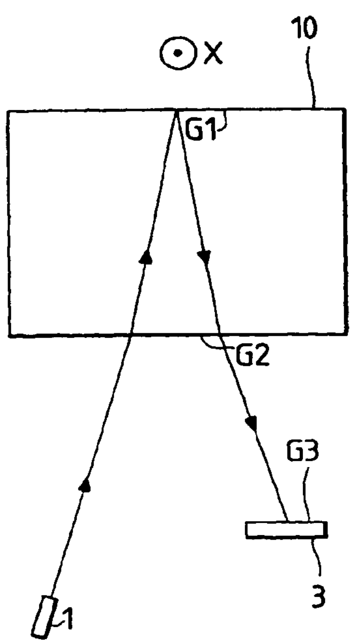


FIG. 4B

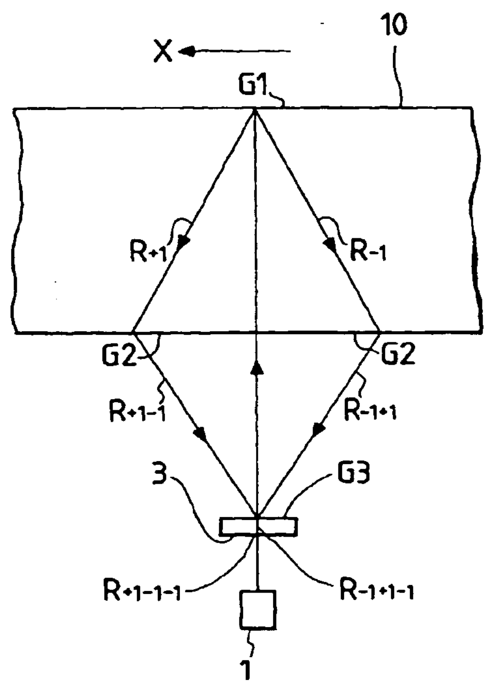


FIG. 5

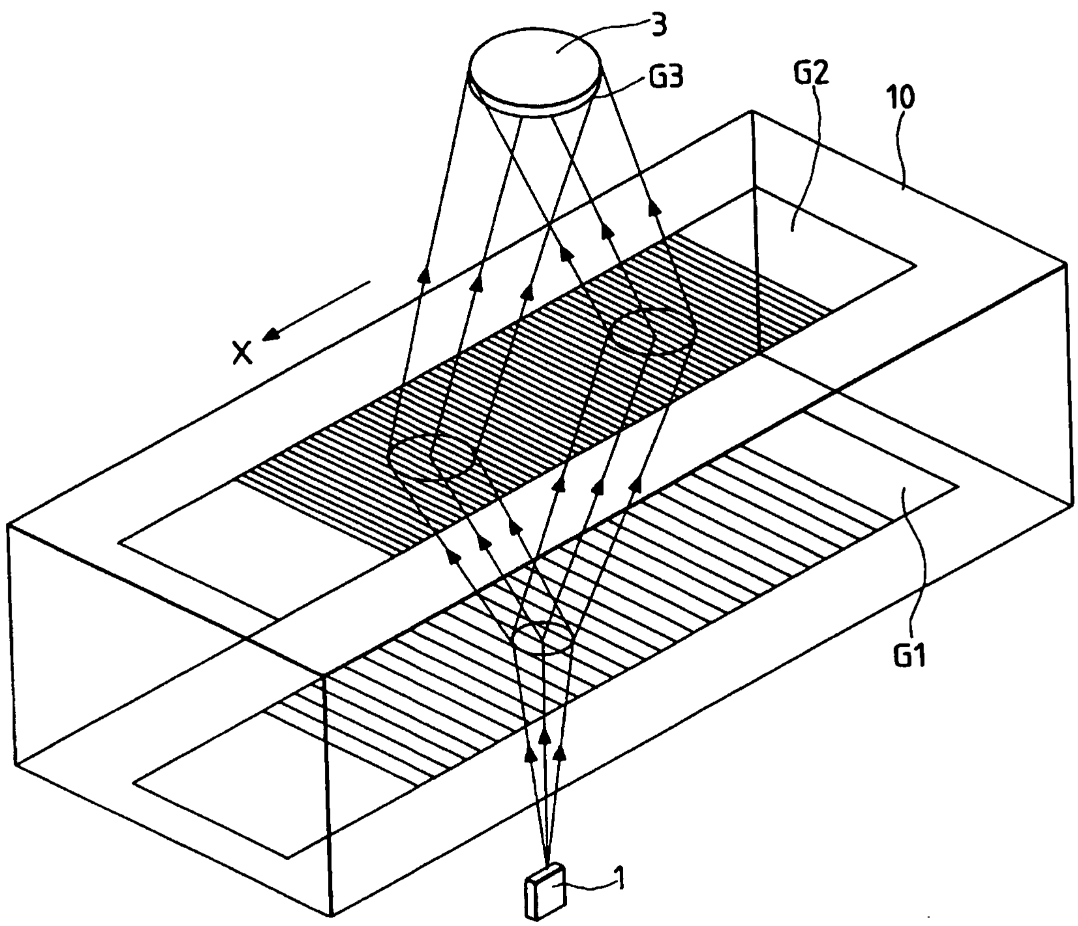


FIG. 6A

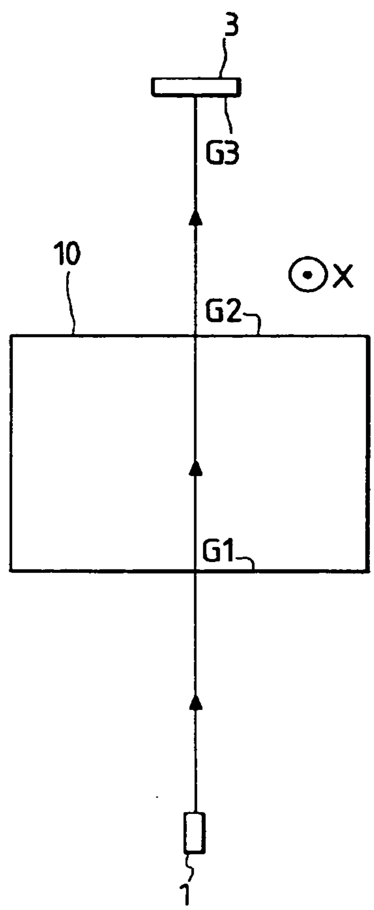
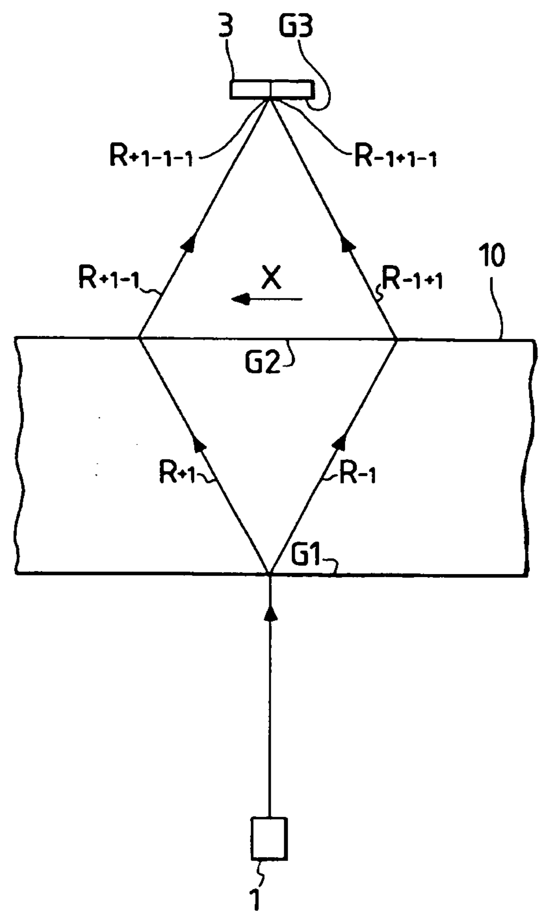


FIG. 6B



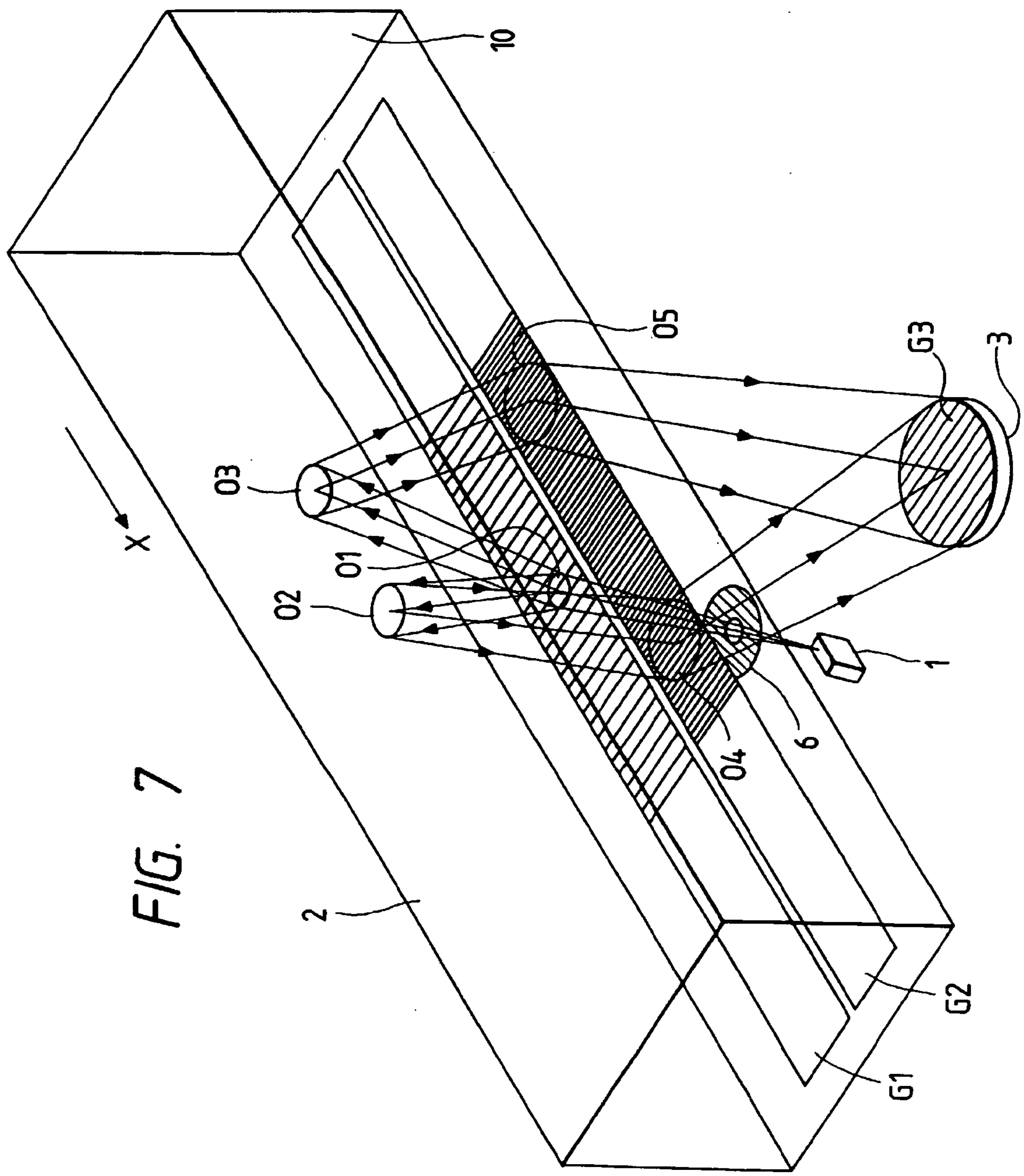


FIG. 7

FIG. 8A

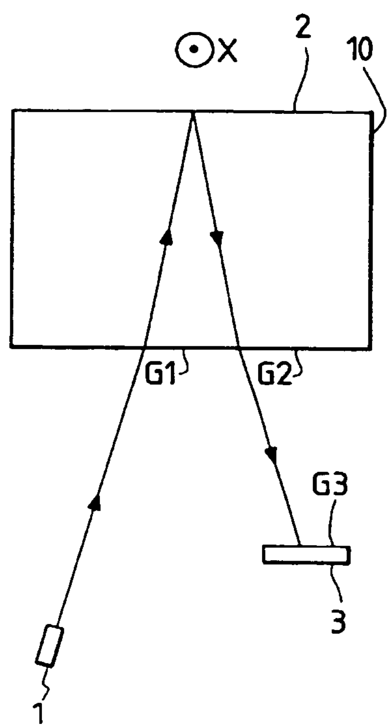


FIG. 8B

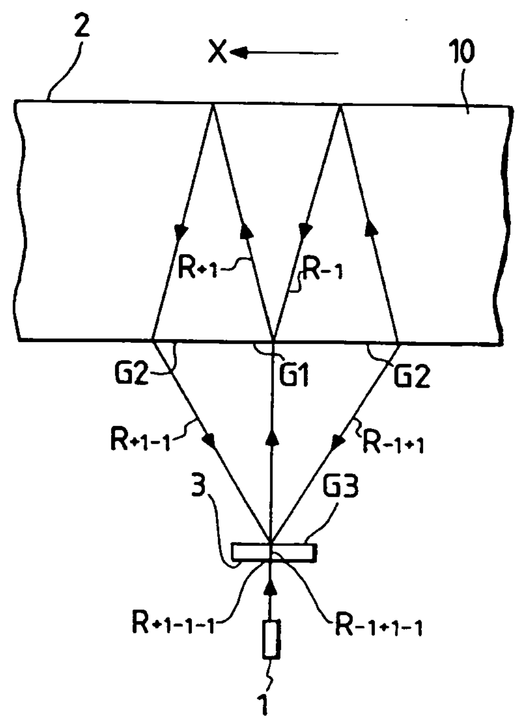


FIG. 9

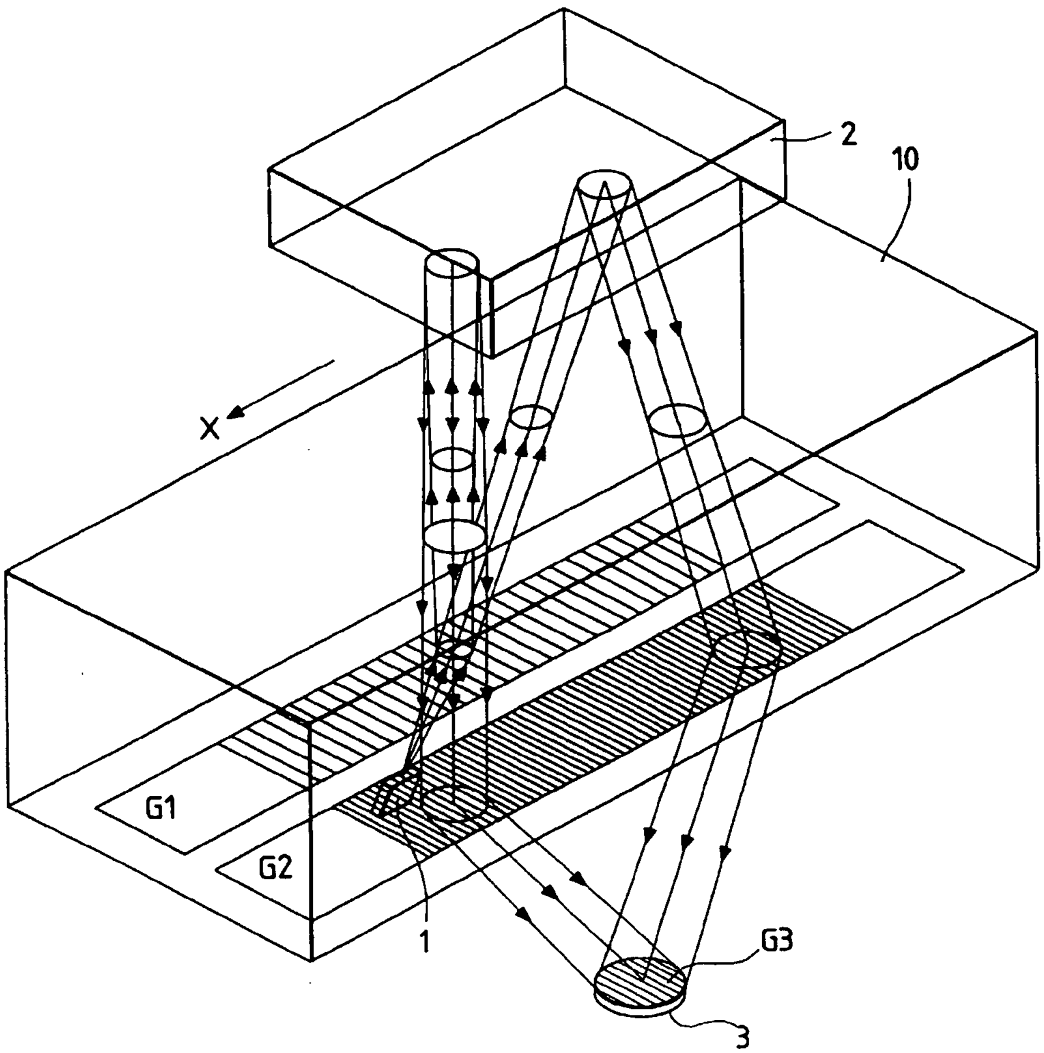


FIG. 10A

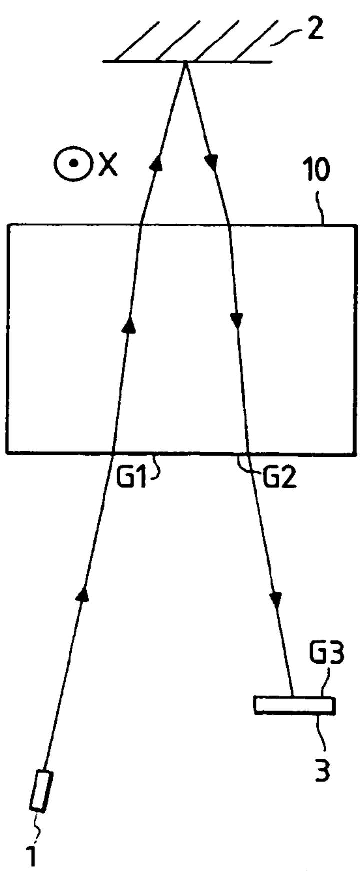


FIG. 10B

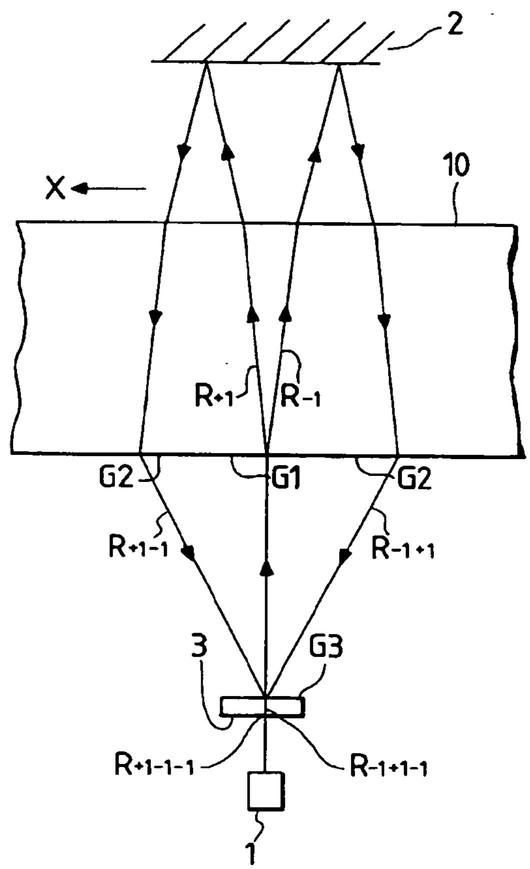


FIG. 11

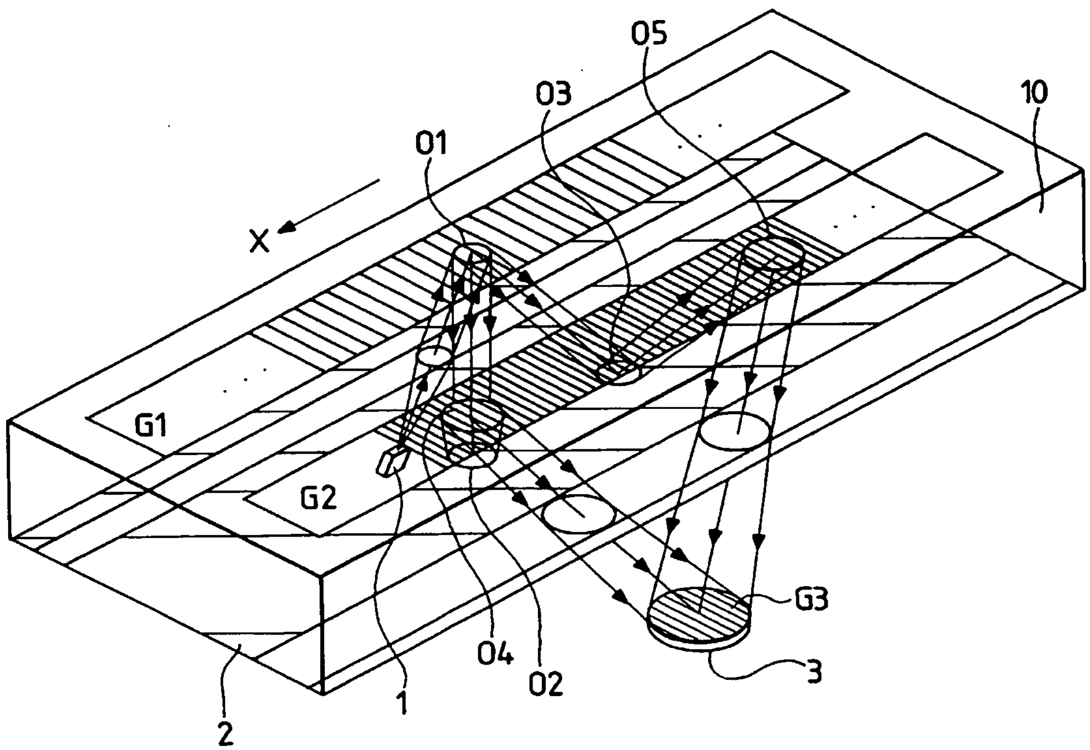


FIG. 12A

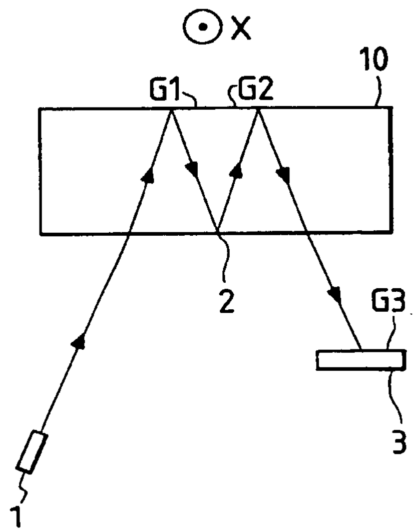


FIG. 12B

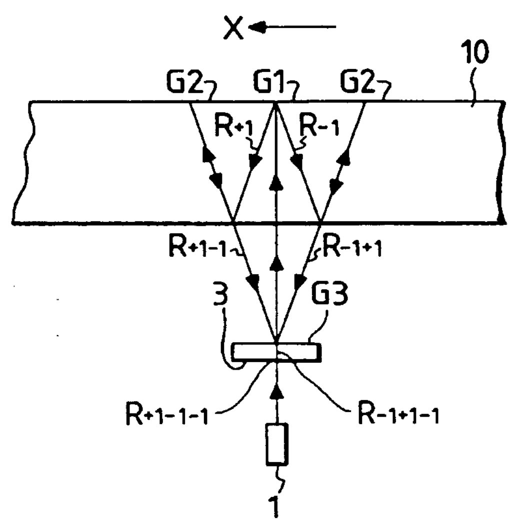


FIG. 13

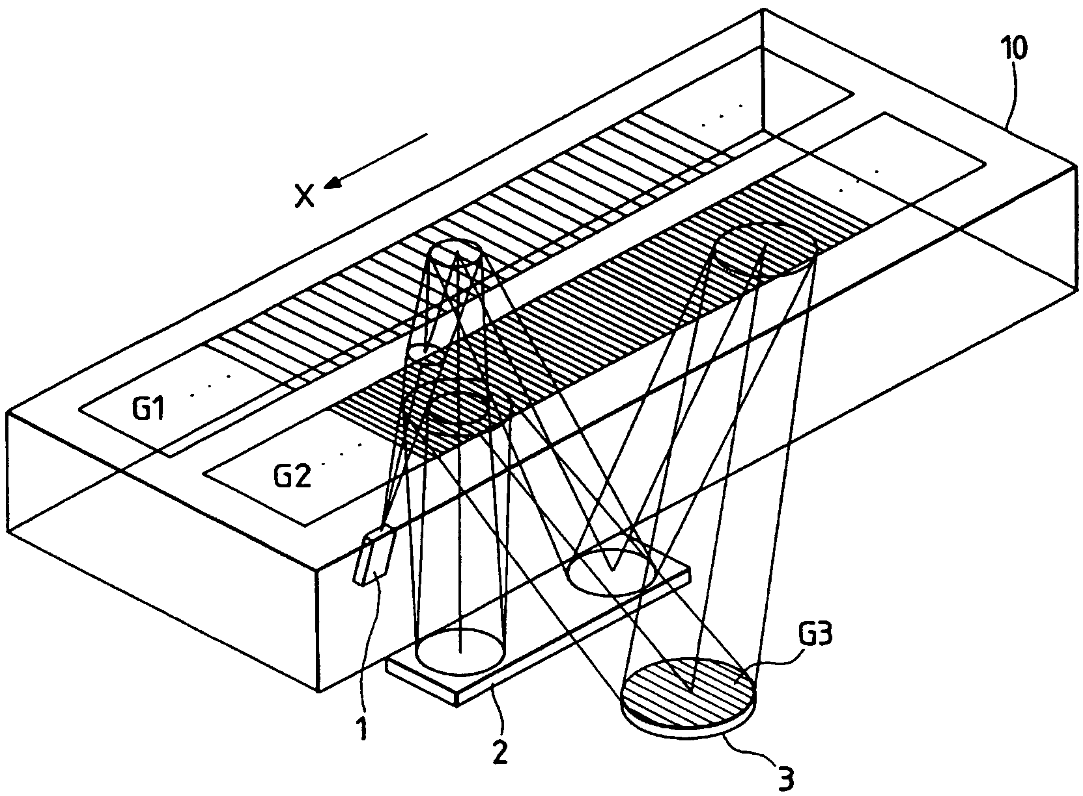


FIG. 14A

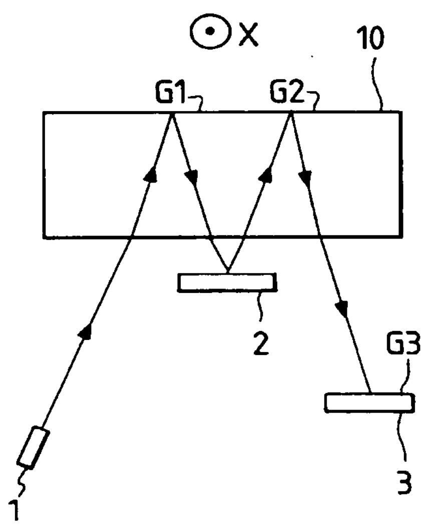


FIG. 14B

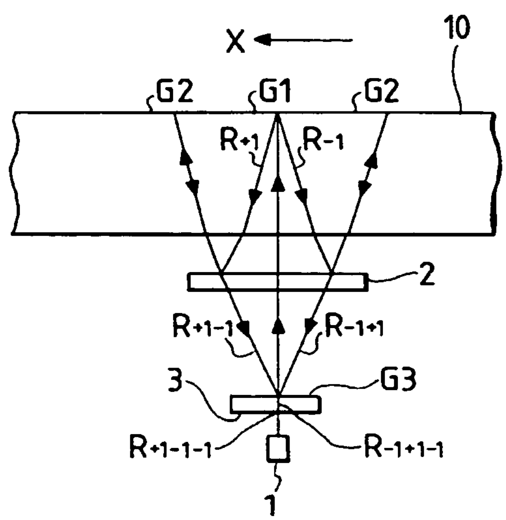
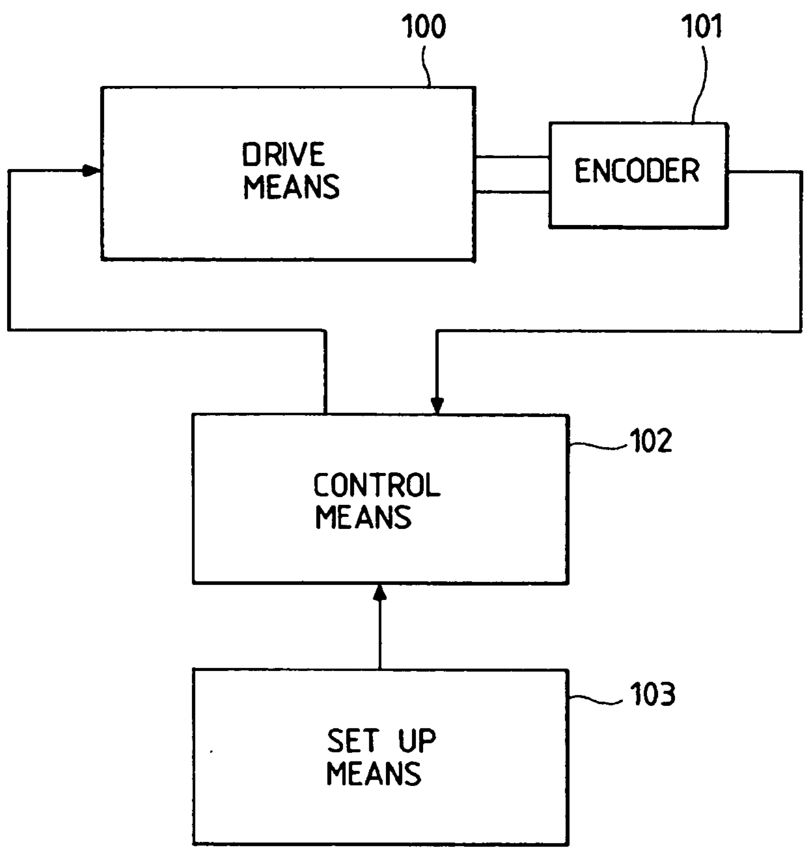


FIG. 15


100
101
DRIVE MEANS
ENCODER
CONTROL MEANS
102
SET UP MEANS
103